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INDUSTRIAL USES OF LIMESTONE AND DOLOMITE

BY

OLIVER BOWLES AND NAN C. JENSEN

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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By Oliver Bowles[2] and Nan C. Jensen[3]

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INTRODUCTION

Limestone (which consists essentially of calcium carbonate) and dolomite (calcium magnesium carbonate) occur widely in the United States. Their presence is of vast economic importance, because they are used much more extensively than any other form of rock. In 1945, limestone (which, broadly, includes dolomite) was quarried in every State except Delaware, New Hampshire, North Dakota, and Rhode Island, and also in Hawaii and Puerto Rico. Total production (including that used in cement and lime manufacture) exceeded 151,700,000 tons, or 79 percent of the quantity of all kinds of stone sold or used during that year.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7402."

[2] Chief, Nonmetal Economics Division, Bureau of Mines.

[3] Nonmetal Economics Division, Bureau of Mines.

Important well-known uses of limestone are as concrete aggregate, road material, railroad ballast, for liming the land, for cement manufacture, as riprap for shore protection, harbor work, and spillways at dams, and as building stone. None of these uses, however, are considered herein. The purpose of this paper is to discuss the industrial and chemical uses that are less widely known and yet are of tremendous importance in a great variety of processing industries. Important examples are dolomite as a refractory furnace lining and limestone as a fluxing agent in blast furnaces, and as a raw material employed in sugar, paper, glass, and alkali manufacture.

PRIOR REPORT

In May 1941, the Bureau issued a report[4] that described these uses in some detail. As new and important developments have taken place during the ensuing years, a revision and representation of the salient features of these uses seem desirable. Asphalt filler and mineral wool uses included in the earlier report are omitted from this paper because they are identified more closely with the highway and building industries, respectively, than with the industrial applications.

COMPOSITION

Limestone, a sedimentary rock of wide occurrence in nature, consists essentially of calcium carbonate ($CaCO_3$) - the mineral calcite - or of a mixture of the carbonates of calcium and magnesium. When 10 percent or more is magnesium carbonate ($MgCO_3$), the rock is termed "magnesium" limestone or "dolomitic" limestone; if the amount approaches 45 percent, the rock is composed essentially of the double carbonate of lime and magnesium ($CaCO_3.MgCO_3$) - the mineral dolomite. The principal impurities in limestone are sand, clay, and iron oxide. Marble is similar in composition and can be used in the same processes as limestone.

LIME INCLUDED WITH LIMESTONE

Lime is made by calcining limestone. Lime manufacture may, therefore, be regarded as an important branch of the limestone industry, so important, in fact, that the Bureau of Mines includes each year a chapter on Lime in the Minerals Yearbook which is separate from the chapter on Stone. To obtain a complete picture of the use of limestone in industry, consideration must be given not only to the limestone sold to or used directly in industry, but also to that which is first calcined into lime and thereafter employed in the chemical and processing industries. The over-all statistics according to use presented herein include both raw limestone and the limestone equivalent of lime so employed. The limestone equivalent of lime is determined on the basis of the approximate requirement of 2 tons of limestone to make 1 ton of lime.

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[4] Bowles, Oliver, and Jensen, Mabel S., Limestone and Dolomite in the Chemical and Processing Industries: Bureau of Mines Inf. Circ. 7169, 1941, 15 pp.

STATISTICAL HISTORY OF PRINCIPAL INDUSTRIAL USES

Table 1 presents a 25-year history of the more important uses of limestone in industry. For the major uses, the history is fairly complete and enables one to study the trends in use over the past quarter of a century. For some of the smaller uses, the history is more fragmentary, but even scattered figures are useful in evaluating the past, present, and possible future importance of these uses.

INDUSTRIAL APPLICATIONS

Table 2 presents the production of limestone applied in the chemical and processing industries for the most recent year for which statistics are now available (1945), according to use, showing the percentage of the total applied to each use. Of the 151,700,000 tons of limestone sold or used in 1945 for all purposes, 49,800,000, or approximately one-third of the total, was used in the chemical and processing industries. The first seven items given in this table account for 93 percent of the total stone used in the industries enumerated; the remaining 7 percent, roughly 3-1/2 million tons, is divided among many industries. The quantities used by them are relatively so small that they would appear to be of minor consequence. However, the importance of limestone to industry cannot be measured merely by its tonnage or money value, because for many industries limestone is an essential raw material for which it is impractical to use any substitute.

The Bureau of Mines is not at liberty to publish figures where the number of producers is so small that confidential data would be revealed. Therefore, it has been necessary to omit a number of uses from the table. The minor uses, enumerated in footnote 11 of the table, consumed 185,830 short tons of limestone and limestone equivalent of lime in 1945.

The balance of the report following this table comprises a discussion of the various uses of limestone in industry, the specifications for each use, and the principal localities from which limestone for each major use is obtained.

TABLE 1. - Quantity of limestone and the limestone equivalent of lime sold or used by producers in the United States for the principal chemical and processing applications, 1921-45, in short tons

Year	Metallurgy[1/] (flux)	Alkali	Refractory (dolomite)	Paper[2/]	Calcium carbide[3/]	Glass	Water purification	Fertilizer filler	Sugar
1921	10,983,150	1,757,790	294,810	592,170	266,450	206,670	148,400	....	595,290
1922	19,091,870	2,526,500	844,320	769,890	256,190	290,440	174,860	....	404,220
1923	26,308,180	3,393,980	921,170	829,360	287,790	355,260	184,810	....	500,620
1924	20,356,780	2,976,820	966,330	738,480	342,510	322,900	227,150	....	652,350
1925	23,662,880	3,611,160	1,200,000	863,070	341,370	470,180	231,550	(4/)	509,760
1926	24,666,170	3,609,590	1,284,730	1,049,100	402,020	494,810	278,960	(4/)	447,680
1927	22,472,950	3,887,710	1,182,990	1,148,220	371,030	405,200	248,420	(4/)	515,970
1928	24,102,590	4,245,100	1,420,370	1,013,720	347,800	433,580	291,510	(4/)	532,420
1929	25,494,260	5,047,260	1,492,460	1,095,910	401,510	407,940	312,230	5/3,910	529,510
1930	17,852,730	4,461,430	1,156,830	1,006,230	417,410	350,000	323,610	5/12,240	452,150
1931	10,255,500	3,368,450	756,040	767,800	211,990	277,520	320,770	(4/)	490,010
1932	4,286,210	3,227,650	343,710	671,550	233,720	211,000	285,190	(4/)	553,240
1933	5/8,514,490	4,213,050	720,160	805,900	164,230	364,990	349,390	....	642,730
1934	5/9,899,690	3,869,450	949,920	849,760	377,210	313,680	367,160	....	520,960
1935	13,097,180	4,127,250	1,232,380	877,150	392,410	434,360	407,680	39,590	501,210
1936	18,870,030	4,430,680	1,594,820	1,049,610	497,620	492,400	438,800	5/38,380	575,980
1937	22,700,880	4,888,030	1,812,310	1,218,270	691,750	609,650	424,430	74,400	609,040
1938	10,679,170	3,658,790	997,180	1,027,490	478,360	424,240	372,420	121,130	664,920
1939	18,769,270	4,671,630	2,168,050	1,231,070	445,330	537,040	502,390	116,080	659,390
1940	24,855,340	4,878,970	2,593,770	1,467,440	658,970	636,810	532,180	233,990	596,740
1941	30,166,320	5/5,888,260	3,119,960	1,716,060	741,080	754,800	638,490	5/301,650	670,790
1942	33,412,440	6,365,120	3,812,800	1,648,080	835,640	815,240	671,750	226,910	680,830
1943	35,371,590	6,883,210	3,659,010	1,471,630	1,237,100	921,260	5/791,660	276,410	389,530
1944	34,536,200	6,998,180	3,656,630	1,440,270	1,463,480	934,310	5/749,580	373,970	299,990
1945	30,524,920	5/7,076,330	3,401,760	1,374,650	1,279,400	998,320	5/804,320	401,160	389,480

Please see footnotes at end of table.

TABLE 1. - Quantity of limestone and the limestone equivalent of lime sold or used by producers in the United States for the principal chemical and processing applications, 1921-45, in short tons (Cont'd.)

Year	Limestone whiting6/	Magnesia	Mineral food (stock feed)	Coal-mine dusting	Insecticides, fungicides, and disinfectants	Tanneries	Sewage and trade-wastes treatment	Miscellaneous filler (not whiting substitute)7/
1921	29,560	5/32,050	....	....	15,960	95,680	6,840	....
1922	66,200	5/53,170	....	....	19,370	85,960	8,240	....
1923	81,310	5/116,410	(4/)	....	5/21,940	107,810	2,950	....
1924	66,910	5/98,160	(4/)	3,020	24,250	106,700	14,790	....
1925	82,290	5/98,980	6,080	15,550	36,570	125,870	18,610	....
1926	95,650	5/72,850	13,030	26,620	39,980	133,070	5,460	....
1927	124,840	5/69,940	5/30,470	28,410	5/44,310	127,330	4,830	....
1928	95,400	5/94,200	5/39,460	54,460	5/38,540	128,930	5,710	....
1929	125,430	5/84,750	5/25,270	34,650	5/53,780	134,090	9,070	....
1930	119,350	5/111,740	5/30,350	47,750	5/51,240	113,050	5,800	....
1931	73,420	5/80,820	5/21,880	38,040	5/42,390	109,210	23,050	....
1932	76,020	5/62,930	5/23,060	25,400	5/44,380	91,890	(4/)	15,070
1933	93,070	92,820	26,860	34,080	5/44,860	141,320	(4/)	13,940
1934	97,340	92,690	35,870	43,000	5/58,640	125,490	(4/)	13,850
1935	5/147,910	106,740	42,980	52,660	5/76,860	142,760	(4/)	55,850
1936	179,110	137,560	53,830	53,480	5/95,200	145,700	8,380	78,490
1937	194,080	116,910	67,230	64,610	91,930	123,090	7,950	20,890
1938	145,170	100,200	65,570	50,890	87,840	119,710	17,390	61,970
1939	175,460	151,440	68,580	68,260	93,820	140,890	33,840	84,910
1940	207,910	171,530	93,160	99,300	109,260	144,830	38,320	93,670
1941	5/417,750	208,180	115,400	136,180	163,910	186,310	76,510	68,980
1942	5/326,930	166,920	169,880	193,260	132,660	157,490	51,520	107,760
1943	296,370	8/269,430	5/293,490	194,360	150,250	138,440	35,320	178,250
1944	352,490	8/275,210	265,590	196,470	158,760	165,450	128,380	236,720
1945	343,220	8/342,830	313,180	216,160	165,010	162,430	142,990	138,750

Please see footnotes at end of table.

TABLE 1. - Quantity of limestone and the limestone equivalent of lime sold or used by producers in the United States for the principal chemical and processing applications, 1921-45, in short tons (Cont'd.)

Year	Poultry grit	Petroleum refining	Chromates and bi-chromates	Coke and gas (gas purification and plant by-products)	Bleach, liquid and powder 9/	Paints and varnish	Explo-sives	Brick, silica (refractory)	Brick, sand-lime and slag	Filter beds
1921	11,780	770	....	19,300	25,100	5/2,890	....	14,250	10,930	(4/)
1922	10,790	1,870	....	28,680	41,960	5/5,010	(4/)	23,410	57,220	(4/)
1923	13,080	2,040	....	23,780	56,400	11,660	(4/)	27,990	29,710	(4/)
1924	6,780	(4/)	....	50,280	68,260	9,510	(4/)	20,990	53,100	(4/)
1925	17,050	(4/)	(4/)	58,000	36,390	7,790	(4/)	51,800	50,290	(4/)
1926	17,450	(4/)	(4/)	53,360	30,890	4,310	(4/)	29,760	79,640	(4/)
1927	33,350	14,200	(4/)	59,980	32,060	10,100	....	31,280	86,130	271,800
1928	18,110	(4/)	(4/)	62,020	67,850	10,030	....	31,470	95,050	41,230
1929	34,600	(4/)	(4/)	68,450	51,800	10,220	....	36,780	85,080	72,870
1930	45,920	(4/)	(4/)	50,430	41,350	8,220	(4/)	29,860	59,010	30,860
1931	31,320	(4/)	(4/)	45,170	42,890	12,190	(4/)	17,750	35,060	56,100
1932	14,960	(4/)	(4/)	34,450	38,750	19,590	(4/)	5,940	27,050	81,600
1933	24,550	(4/)	(4/)	45,530	5/31,130	13,600	(4/)	17,490	8,700	(4/)
1934	26,320	(4/)	(4/)	46,890	5/26,560	23,640	(4/)	14,790	16,890	93,020
1935	30,290	(4/)	(4/)	41,830	21,480	29,410	(4/)	18,230	22,800	49,860
1936	22,820	25,000	16,530	52,210	25,590	35,590	(4/)	10/25,730	10/36,820	98,690
1937	27,360	20,320	22,430	43,980	18,280	54,480	(4/)	10/25,770	10/41,490	34,970
1938	31,260	13,830	27,650	29,690	33,690	25,180	(4/)	10/11,470	10/28,830	142,050
1939	39,010	56,000	(4/)	26,460	21,150	55,070	(4/)	21,890	50,730	105,850
1940	38,910	58,690	(4/)	28,280	21,220	65,250	(4/)	30,710	39,240	61,290
1941	62,070	69,390	36,550	44,020	29,370	92,750	(4/)	49,930	43,010	32,950
1942	62,620	61,890	41,080	35,260	26,320	29,180	(4/)	35,010	41,100	66,310
1943	119,080	57,460	45,940	61,090	23,240	17,300	20,190	30,410	11,960	36,260
1944	130,450	68,250	69,350	54,780	23,940	22,410	42,430	31,860	6,240	20,880
1945	114,670	106,350	72,500	62,350	49,420	38,630	31,060	30,660	25,280	20,920

Please see footnotes at end of table.

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TABLE 1. - Quantity of limestone and the limestone equivalent of lime sold or used by producers in the United States for the principal chemical and processing applications, 1921-45, in short tons (Cont'd.)

Year	Glue	Medicines and drugs	Creameries and dairies	Rubber manufacture	Soap and fat	Gelatin	Miscellaneous food products 11/	Grease, lubricating	Salt refining	Wood distillation
1921	8,030	(4/)	1,470	1,450	5/28,500	2,570	5/2,230	19,170	2,140	4,940
1922	9,890	....	450	3,850	5/39,230	......	5/450	7,950	2,560	11,930
1923	20,970	....	780	1,530	5/48,880	(4/)	5/1,320	12,510	1,940	17,540
1924	12,940	(4/)	3,090	3,260	5/71,690	(4/)	5/370	......	2,960	11,740
1925	23,480	....	4,170	7,140	5/40,850	(4/)	5/830	......	2,200	5,610
1926	22,240	....	5,440	7,080	5/41,430	(4/)	5/1,050	......	3,440	24,450
1927	15,730	....	(4/)	8,380	5/58,770	(4/)	(4/)	......	2,420	23,360
1928	16,930	(4/)	(4/)	6,720	5/85,760	(4/)	(4/)	......	4,850	7,800
1929	19,770	(4/)	(4/)	9,580	5/103,120	(4/)	(4/)	......	4,370	8,890
1930	14,390	(4/)	(4/)	8,400	5/93,830	(4/)	(4/)	......	7,500	5,580
1931	12,780	(4/)	(4/)	5,800	5/59,150	(4/)	(4/)	......	6,070	2,200
1932	6,530	(4/)	(4/)	4,620	64,450	(4/)	5/13,770	(4/)	3,010	3,510
1933	6,970	....	(4/)	4,120	58,000	4,230	5/18,380	(4/)	5/10,280	3,120
1934	12,460	....	(4/)	5,550	45,850	2,300	5/17,270	(4/)	5/14,320	6,920
1935	14,430	....	(4/)	5,250	58,220	8,390	5/14,710	(4/)	5/11,880	8,530
1936	17,790	....	(4/)	6,910	50,400	10,340	5/26,470	......	12,490	8,870
1937	15,760	....	(4/)	3,460	55,270	9,980	5/21,330	(4/)	10,740	12,060
1938	12,910	....	(4/)	2,660	39,910	11,850	5/12,400	(4/)	8,630	2,020
1939	13,860	(4/)	1,360	2,710	19,120	13,170	13,910	6,150	13,120	2,950
1940	16,110	....	510	3,760	13,710	8,170	5,770	3,230	10,760	4,910
1941	24,010	(4/)	2,340	6,120	(4/)	9,690	1,770	8,000	3,910	5,110
1942	15,770	12,040	2,850	2,760	13,350	14,450	17,900	9,990	8,230	5,800
1943	18,930	9,840	7,330	4,080	11,490	10,550	9,070	14,780	9,300	3,700
1944	18,260	13,410	13,220	11,270	12,070	13,670	11,850	2,590	11,000	1,490
1945	18,300	15,790	14,600	14,340	10,440	10,050	9,170	4,140	3,770	2,530

Please see footnotes at end of table.

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TABLE 1. - Quantity of limestone and the limestone equivalent of lime sold or used by producers in the United States for the principal chemical and processing applications, 1921-45, in short tons (Cont'd.)

Year	Acetic acid, carbolic acid, and carbonic acid	Acid neutralization	Alcohol	Calcium acetate	Calcium carbonate (precipitated)	Polishing compounds	Textiles	Tobacco
1921	5/125,640	(4/)	(4/)	7,450	....	(4/)	(4/)	......
1922	30,840	....	(4/)	27,000	(4/)	(4/)	....	......
1923	46,900	4,750	(4/)	25,670	....	(4/)	(4/)	......
1924	38,390	(4/)	18,360	8,250	....	....	4,770	......
1925	46,950	(4/)	1,360	21,050	....	(4/)	2,060	......
1926	(4/)	(4/)	6,590	14,260	....	(4/)	2,270	(4/)
1927	5/8,860	(4/)	4,400	19,240	....	(4/)	2,260	......
1928	5/4,690	(4/)	4,600	3,290	....	(4/)	2,920	......
1929	5/4,560	(4/)	620	42,270	....	(4/)	5,710	......
1930	5/2,290	(4/)	4,320	6,210	....	(4/)	5,560	......
1931	5/2,670	(4/)	4,340	5,000	....	(4/)	2,480	(4/)
1932	(4/)	(4/)	4,030	6,000	....	(4/)	1,470	(4/)
1933	(4/)	5/11,830	(4/)	12,510	....	2,280	....	6,150
1934	(4/)	5/17,270	(4/)	10,150	....	4,850	(4/)	6,780
1935	(4/)	5/8,690	(4/)	7,000	....	6,210	(4/)	7,420
1936	(4/)	5/6,220	(4/)	6,110	....	7,010	(4/)	7,830
1937	(4/)	5/6,870	(4/)	(4/)	(4/)	7,100	(4/)	......
1938	(4/)	5/10,150	(4/)	(4/)	(4/)	4,610	(4/)	......
1939	(4/)	(4/)	1,890	....	11,200	6,990	2,510	9,050
1940	....	(4/)	5,060	....	12,070	12,690	3,100	10,750
1941	....	5/3,480	(4/)	....	11,580	7,840	2,180	(4/)
1942	....	5/10,360	(4/)	....	(4/)	1,520	1,740	13,720
1943	....	5/35,530	(4/)	....	(4/)	(4/)	990	(4/)
1944	....	(4/)	(4/)	....	(4/)	(4/)	(4/)	(4/)
1945	....	(4/)	(4/)	....	(4/)	(4/)	(4/)	(4/)

Please see footnotes on next page.

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Footnotes to table 1.

1/ Includes flux, ore concentration (flotation, cyanidation, bauxite purification, and magnesium manufacture), wire drawing, and other metallurgical uses.
2/ Includes bleach used in paper mills.
3/ 1939-45: Calcium carbide and cyanamide.
4/ Bureau of Mines not at liberty to publish figures. To avoid disclosing confidential information, the quantity is included under "Other uses" or "Undistributed" in the use tables appearing in the Stone or Lime chapters of the Minerals Yearbook for the respective year.
5/ Incomplete data. To avoid disclosing confidential information, the lime or limestone entering into some products is included under "Other uses" or "Undistributed" in the use tables appearing in the Stone or Lime chapters of the Minerals Yearbook for the respective year.
6/ Includes filler for calcimine, caulking compounds, chewing gum, cosmetics, crayons, explosives, flavoring extracts, foundry facing powder, graphite, leather goods, linoleum, paint, paper, phonograph records, plastics, pottery, putty, roofing, rubber, sealing wax, tanning, tile, tooth paste, tooth powder, wire coating, and unspecified uses.
7/ Does not include asphalt filler or fertilizer filler.
8/ Includes dolomite for refractory magnesia.
9/ Excludes bleach used in paper mills.
10/ Slag brick included with silica brick.
11/ Includes chocolate, cocoa, fruit juices, phosphate baking powders, and unspecified food products.

TABLE 2. - Limestone and the limestone equivalent of lime sold or used by producers in the United States in chemical and processing applications in 1945, by uses

Use	Short tons	Percent of total
Metallurgical (flux)1/	30,524,920	62.4
Alkali	2/7,076,330	14.5
Refractory (dolomite)	3,401,760	7.0
Paper3/	1,374,650	2.8
Calcium carbide and cyanamide ...	1,279,400	2.6
Glass	998,320	2.0
Water purification	4/804,320	1.7
Fertilizer filler	401,160	0.8
Sugar	389,480	0.8
Limestone whiting5/	343,220	0.7
Magnesia6/	342,830	0.7
Mineral food	313,180	0.6
Coal-mine dusting	216,160	0.5
Insecticides, fungicides, and disinfectants	165,010	0.3
Tanneries	162,430	0.3
Sewage and trade-wastes treatment	142,990	0.3
Miscellaneous filler (not whiting substitute)7/	138,750	0.3
Poultry grit	114,670	0.2
Petroleum refining	106,350	0.2
Chromates and bichromates	72,500	0.2
Coke and gas (gas purification and plant byproducts)	62,350	0.1
Bleach, liquid and powder8/	49,420	0.1
Paints and varnish	38,630	(9/)
Explosives	31,060	(9/)
Brick, silica (refractory)	30,660	(9/)
Brick, sand-lime and slag	25,280	(9/)
Filter beds	20,920	(9/)
Glue	18,300	(9/)
Medicines and drugs	15,790	(9/)
Creameries and dairies	14,600	(9/)
Rubber manufacture	14,340	(9/)
Soap and fat	10,440	(9/)
Gelatin	10,050	(9/)
Miscellaneous food products10/	9,170	(9/)
Grease, lubricating	4,140	(9/)
Salt refining	3,770	(9/)
Wood distillation	2,530	(9/)
Other uses11/	185,830	0.4
	48,915,710	100.0
Unspecified uses12/	884,910	.....
Total	49,800,620	.....

1/ Includes flux, ore concentration (flotation, cyanidation, bauxite purification, and magnesium manufacture), wire drawing, and other metallurgical uses. 2/ Limestone only. To avoid disclosing confidential information, limestone equivalent of lime sales is included under "Other uses." 3/ Includes bleach used in paper mills. 4/ Limestone equivalent of lime only. To avoid disclosing confidential information, limestone sales are included under "Other uses." 5/ Includes filler for calcimine, caulking compounds, crayons, explosives, leather goods, linoleum, paint, paper, phonograph records, plastics, pottery, putty, roofing, rubber, tanning, tooth paste, and wire coating. 6/ Includes dolomite for refractory magnesia.

7/ Does not include asphalt filler or fertilizer filler. 8/ Excludes bleach used in paper mills. 9/ Less than 0.1 percent. 10/ Includes chocolate, cocoa, fruit juices, phosphate baking powders, and unspecified food products. 11/ Includes acid neutralization, alcohol, calcium carbonate (precipitated), carbon dioxide, miscellaneous chemicals, magnesium metal, oil-well drilling, polishing compounds, rayon, retarder, rice milling, sulfur, textiles, tobacco, and wool pullers. 12/ Includes some limestone used for other than chemical and processing applications.

Metallurgy (Flux)

Enormous quantities of lime and limestone are consumed annually as fluxing material in blast furnaces, open-hearth and electric steel plants, and to a smaller degree in nonferrous metallurgy. Most iron ores carry alumina and silica as impurities, and the addition of a basic flux such as limestone is necessary to form a slag with them. The limestone also removes sulfur, which is an impurity in iron and steel. It is evident, therefore, that limestone, to be efficient as a flux, should be relatively free from alumina and silica. If more than small percentages of these elements are present, the stone is less effective, increases slag volume and fuel consumption, and slows production.

The element of cost, however, is an important factor in the purity of stone used. As silica and alumina are not classed as harmful impurities but simply as diluents, it may be more economical to use a conveniently located low-cost stone relatively high in these impurities than to use a much purer stone that must be shipped in from more distant points with consequent higher delivered cost.

In 1945, fluxing stone was reported from 34 States, and sales totaled 27,639,520 short tons, or 18 percent of the total limestone sold or used for all purposes. The largest producing States were Michigan, with 31 percent of the total output; Pennsylvania, 30 percent; Ohio, 18 percent; West Virginia, 7 percent; and Alabama, 6 percent. Limestone used as flux comprised over half of the total limestone tonnage reported in each of the above States, with the exception of Ohio. Seventy-nine percent of all flux sold was used in blast furnaces; 18 percent in open-hearth steel plants; 2 percent in copper, gold, lead, zinc, and unspecified smelters; and 1 percent in foundries and in cupola and electric furnaces.

Lime is also used extensively as a metallurgical flux, particularly in open-hearth steel plants. Open hearths and electric furnaces consumed 1,064,005 tons and nonferrous smelters 7,442 tons in 1945. The chief producing States, in order of importance, were West Virginia, Pennsylvania, Alabama, Missouri, Ohio, and Illinois.

Alkali

In the manufacture of soda ash by the ammonia-soda process, about 1-1/4 tons of high-calcium limestone are used for each ton of soda ash produced. The stone is calcined at the chemical plant, and both the lime and carbon dioxide gas are used. Stone ranging from 1 to 6 inches in diameter is desired.

Limestone for alkali manufacture should be pure enough to yield, upon calcination, a product containing not less than 85 percent available lime as determined by the modified Scaife method.[5] Also, the resulting lime should contain not more than 3 percent magnesium oxide.

A large proportion of the limestone produced for use in alkali works is captive tonnage; that is, it is produced by the industry that uses it. For a number of years, Michigan and New York were the only States producing high-calcium stone for this use; but in 1945, 12 companies operating 15 plants reported tonnage from 8 States. Alpena, Presque Isle, and Wayne Counties, Mich., with an output of 4,030,730 short tons in 1945, or 57 percent of the total of 7,076,330, constitute the area of largest production in the United States. Other producing centers, according to rank of importance in output are Erie and Onondago Counties, N. Y.; Calcasieu and Winn Parishes, La.; Smyth County, Va.; Bexar and Comal Counties, Tex.; Summit County, Ohio; El Dorado and San Bernardino Counties, Calif.; and Shelby County, Ala. Relatively small quantities of lime are sold for alkali manufacture.

Refractories

Dolomite and high-magnesium limestone are used widely as substitutes for magnesite refractories in basic open-hearth steel and other metallurgical furnaces. Dead-burned material in various forms is commonly used, although raw dolomite may be employed for repair work. The refractory stone shown in table 2 includes raw stone and the raw-stone equivalent of the dead-burned product.

Where dead-burned dolomite is used as a substitute for dead-burned magnesite in basic furnace bottoms, the raw stone should contain not more than 1 percent of silica, not more than 1.5 percent of combined iron oxide and alumina, and at least 35 percent of magnesium carbonate. The specifications for raw dolomite for patching purposes need not be quite so rigid. Sales of raw stone (1,027,090 short tons) in 1945 were reported by 12 companies operating 14 plants in the following 11 States: Colorado, 1; Illinois, 3; Indiana, 1; Massachusetts, 1; Michigan, 1; Nevada, 1; New York, 1; Ohio, 1; Pennsylvania, 2; West Virginia, 1; and Wisconsin, 1. Pennsylvania, West Virginia, Illinois, and Colorado, in order of importance, produced 95 percent of the total.

Sales of dead-burned dolomite amounted to 1,187,334 short tons (limestone equivalent approximately 2,374,670 short tons) in 1945 and were reported by 14 companies operating 17 plants in the following 8 States: Alabama, 1; California, 1; Colorado, 1; Illinois, 2; Missouri, 1; Ohio, 7; Pennsylvania, 2; and West Virginia, 2. Ohio, Pennsylvania, West Virginia, and Illinois, in order of importance, produced 89 percent of the total.

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[5] For details of this method, see Proc., Amer. Soc. Testing Materials, vol. 25, Part I (1925), p. 627; or Ind. and Eng. Chem., vol. 20 (1928), pp. 1355-56; or "Recommended Specification for Quicklime and Hydrated Lime for Use in the Purification of Water," Circular of the Bureau of Standards No. 231 (1925).

Paper

Both lime and limestone are used in the paper industry in the preparation of the cooking liquor. By digesting the wood with an acid liquor, all the constituents of the wood chips except cellulose are dissolved and removed. The cooking liquor is produced by the chemical reaction between sulfur dioxide and lime.

For the milk-of-lime method of making sulfite pulp, a high-magnesium or dolomitic lime is preferred. However, if the Jennsen tower system is used, limestone rather than lime is employed, and a high-calcium stone generally gives better service than a high-magnesium stone.

For the soda-pulp and sulfate-pulp processes, a high-calcium lime containing less than 2 percent magnesia is desired. Lime having as much as 7 percent iron oxides, silica, and alumina has been used, but in general the purer the lime the better.

An Interdepartmental Conference established in 1920 a specification for lime to be used in cooking rags for the manufacture of paper, which required that quicklime for such use should contain not less than 95 percent calcium oxide, not more than 2 percent magnesium oxide, not more than 2 percent of the oxides of silicon, iron, aluminum, and other insoluble matter, and not more than 2 percent carbon dioxide. For hydrated lime, these limiting percentages were, respectively, 72, 1.6, 1.6, and 1.6.

Limestone for use in the manufacture of chemical pulp was quarried in 11 States, in order of importance as follows: Washington, Michigan, Pennsylvania, Texas, Maine, Oregon, Virginia, Vermont, Ohio, Wisconsin, and Tennessee. Sales totaled 352,990 short tons in 1945.

Lime sold to paper mills in 1945 totaled 510,832 short tons. The leading States in sales of lime for this use, in order of importance, were Alabama, Pennsylvania, Tennessee, Michigan, Ohio, and Minnesota.

In the soda process of preparing chemical pulp, an important reuse of lime has been developed. The soda liquor, which is separated from the pulp, is concentrated and evaporated to dryness, and the ash is leached for its soda content. It becomes carbonated during the process and is converted into caustic soda, ready for reuse by treating it with lime. The reaction is as follows: $Na_2CO_3 + Ca(OH)_2 = 2NaOH + CaCO_3$. The calcium carbonate settles out as a sludge, which is calcined into lime and is then available for reuse.

It is obvious from the above statement that the quantity of limestone sold to the paper industry is not a true measure of the quantity required per ton of pulp prepared, because a considerable quantity of the limestone is used repeatedly.

Calcium Carbide

Calcium carbide and calcium cyanamide are products of the electric furnace. Calcium carbide is formed when a charge of lime and coke, mixed in the proportion of 60 and 40 percent, respectively, is heated to 2,000° C. Approximately 2 tons of limestone or 1 ton of lime is required for each ton of calcium carbide manufacture. Calcium cyanamide is derived from the carbide by treating it with nitrogen. No cyanamide has been made in the United States in recent years. Calcium carbide is important chiefly because, with water, it forms acetylene, used for lighting and for the steel-cutting and welding torch. One of the newer uses is in the manufacture of synthetic rubber. Calcium cyanamide is a nitrogenous fertilizer.

The use of calcium carbide increased greatly during the war, partly because of the very extensive use of acetylene welding and partly because of the expanded program of synthetic rubber manufacture.

A very pure, high-calcium limestone must be employed in the manufacture of these products, especially if the carbide is to be used for acetylene. The limestone should contain not more than 0.01 percent phosphorus pentoxide, because when phosphates are present undesirable phosphides are formed. The stone also must contain not more than 0.5 percent MgO, because magnesium does not form a carbide, and the presence of its oxide in the charge makes the electrolytic process less efficient. Combined alumina and iron oxide should not exceed 0.5 percent, silica not more than 1.2 percent, and sulfur not more than a trace.

According to compilations made by the Federal Power Commission, 13 plants were producing calcium carbide in the United States during recent years. Plant locations are as follows: Alabama 2, Iowa 2, Kansas 1, Kentucky 1, Michigan 1, New York 1, Ohio 2, Oregon 2, and Virginia 1. One of the Alabama plants (the T. V. A. plant at Wilson Dam) discontinued operation in December 1945.

In 1945, four limestone companies reported production of 549,510 short tons of raw stone sold for the manufacture of calcium carbide: one in Presque Isle County, Mich.; one in Madison County, Ala.; and one each in Giles and Wythe Counties, Va.

Lime for calcium carbide manufacture originated in the following States in order of importance: Missouri, Pennsylvania, Wisconsin, Indiana, Michigan, and Washington. Sales in 1945 (364,944 short tons) were considerably smaller than in 1944, chiefly because of the cut-back in acetylene welding.

Glass

In the manufacture of glass, either lime or limestone of high calcium or high magnesium content may be used. High-calcium limestone is used in making bottle and window glass, whereas dolomitic stone is used for special glasses. Uniform stone must be used for each type of glass in order that the product may have constant chemical and physical properties. Common glass is made from the fused mixture of alkali, lime or limestone (limestone may constitute as much as 30 percent of some glass batches), and silica. Limestone for use in clear, colorless glass products must contain a very low percentage of iron oxide. Silica in moderate quantities is not detrimental, but the sulfur and phosphorus content should be low.

Production of limestone for glass making was confined to 13 States, with Ohio, the leading State, reporting 175,300 short tons, or 31 percent of the total output of 556,610 short tons in 1945. Other leading States in the production of limestone for glass making were, in order of production, Missouri Pennsylvania, Illinois, California, Indiana, Arkansas, Tennessee, Texas, and Washington, with small tonnages reported from Connecticut, Michigan, and Vermont.

In addition to the limestone recorded above, the glass industry used 220,853 short tons of lime in 1945. Ohio produced by far the largest part of the lime so used.

Water Purification

Lime is used extensively for water treatment, particularly for purification and softening of municipal water supplies and for correcting the scale-forming hardness of boiler water.

Either quickline or hydrated lime may be used for these purposes. Limestone as the raw material for making lime to be so used must be reasonably free from alumina, silica, and other impurities. The purity of the stone will, of course, be governed by the requirements of the lime. The specifications of lime for water treatment as recommended by the American Water Works Association are not framed on the basis of percentage of impurities permissible but on the percentage of available lime, which has been discussed previously under "Alkali." The specifications require that quicklime for such use contain at least 85 percent available lime (CaO) and hydrated lime at least 90 percent available calcium hydroxide [$Ca(OH)_2$].

Water purification has become an important use for lime. Sales for such use amounted to 402,158 short tons in 1945. The leading States, in order of production, were Missouri, Pennsylvania, Illinois, Texas, Minnesota, and Ohio.

Fertilizer Filler

The use of limestone as a fertilizer filler has increased greatly during recent years. In 1936 only 38,380 tons were so used. The quantity had increased to over 300,000 tons in 1941 and to 401,160 tons in 1945. The filler reduces the caking of fertilizers and serves as a soil conditioner. Both dolomite and high-calcium limestone are satisfactory for this use.

In 1945, stone for this purpose was reported from 11 States. Virginia, which produced 47 percent of the total, is followed, in rank of importance, by Georgia, Pennsylvania, Maryland, Ohio, California, Illinois, Arkansas, Connecticut, Washington, and Massachusetts.

Sugar

Lime is an indispensable material in the manufacture of beet and cane sugar. Its function is to precipitate impurities from the juices or syrup or to precipitate the sugar from impure solutions. Only high-calcium limestone, containing about 97 percent calcium carbonate and free from impurities that would impart a taste, is desired. Limestone is used in refining beet sugar by the carbonization process. The limestone is burned to lime, and both the lime and carbon dioxide gas are used. Because carbon dioxide as well as lime is necessary to beet-sugar refining, the raw stone is burned at the refinery. For every pound of beet sugar produced, a little more than half a pound of limestone is used in the manufacturing process. Cane-sugar-refining companies buy burned lime because carbon dioxide is not necessary in the refining process.

The reuse of lime is also being practiced in the sugar-refining industry. The Steffen process of refining sugar requires finely powdered quicklime, which precipitates sucrose from an aqueous solution of beet molasses. After the reaction is complete, the addition of carbon dioxide converts the lime into calcium carbonate, which precipitates and is removed by filtering. Filter cake is recalcined less extensively in the sugar than in the paper industry, but recently a continuous process has been perfected whereby recalcination probably will become a more important factor.

The States producing the greatest quantities of limestone for use in sugar manufacture in 1945 were Wyoming, Michigan, and California, which together supplied 55 percent of the total sales of 340,310 short tons. Other producing States were, in order of importance, Colorado, Montana, Utah, Nevada, Nebraska, Iowa, Missouri, South Dakota, and Idaho. A small tonnage was reported in Puerto Rico.

Lime for use in sugar refining, which totaled 24,584 short tons in 1945, was reported chiefly from Hawaii, Michigan, Arkansas, Pennsylvania, Puerto Rico, and Louisiana.

Whiting

The Bureau of Mines considers whiting as divisible into three classes: Limestone and marble whiting, consisting of finely pulverized limestone (or crystalline limestone) of a quality suitable for use as a filler or pigment; chalk whiting, a material prepared from chalk; and precipitated whiting, material prepared as a precipitate from some soluble calcium salt or from a milk of lime suspension that has been recarbonated.

Very few deposits of true chalk suitable for the manufacture of whiting have been exploited in the United States. Virtually all of the chalk whiting used in the United States is imported or is manufactured from imported crude chalk. The use of limestone and marble whiting from domestic sources is becoming increasingly important. The products in which it is used are indicated in footnote 5 to table 2.

Production of ground limestone for whiting was reported in 1945 from 18 States. Ohio, Nebraska, Vermont, Tennessee, and Illinois produced 49 percent of the total stone (343,220 short tons) used for whiting applications. Other States, in rank of importance, were Alabama, New York, Pennsylvania, California, Indiana, Massachusetts, Michigan, Maryland, Oregon, New Jersey, Connecticut, Wisconsin, and Missouri.

Magnesia

Large quantities of dolomite are consumed annually for the manufacture of basic magnesium carbonate (also called technical carbonate, block magnesia, and magnesia alba), which finds its greatest outlet in the manufacture of pipe and boiler covering and general heat insulation. Magnesia recovered from dolomite is also used for making periclase refractories. Sales of dolomite for these uses in 1945 were reported by eight companies operating plants in the following States, in order of importance: California, 2; Pennsylvania, 3; Ohio, 2; and Maryland, 1. Sales totaled 295,540 short tons.

Relatively small quantities of lime are used for magnesia manufacture.

Mineral Food

Calcium is important to the success of livestock farming because it serves as a bone builder, is necessary in the proper functioning of the nervous system, and also acts as a neutralizer in the digestive tract. According to the Kansas State Agricultural College, one-tenth pound of limestone should be consumed each day per head of livestock. A satisfactory limestone for stock food should contain at least 95 percent calcium carbonate, no fluorine, and very little magnesium. The stone must be ground almost as fine as wheat flour.

Production of limestone for mineral food was so small that before 1925 separate figures were not given in Bureau of Mines reports. Production had increased to 68,580 tons by 1939 and to 291,580 tons in 1945.

Production of limestone for mineral food in 1945 was reported from 13 States. Missouri and Illinois produced 49 percent of the total, followed, in rank of importance, by Nebraska, Iowa, Pennsylvania, Ohio, Arkansas, California, Kansas, Virginia, Texas, Vermont, and Washington. Small quantities of lime are also used as mineral food.

Coal-mine Dusting

Several hundred operators of bituminous coal mines employ fine, incombustible dusts for distribution throughout their mines as a means of preventing or checking coal-dust explosions. Limestone dust is particularly satisfactory for this purpose, because it is essentially calcium carbonate, which is not injurious to the lungs, and because, being white, the proportion of inert material present can be estimated readily. Limestone with a high silica content is undesirable. Screen-size specifications are not exacting. Those approved by the Bureau of Mines require that 100 percent shall pass through a 20-mesh screen, and 50 percent through a 200-mesh screen.

As the material commands a low price, it is usually furnished by quarries situated near coal mines. The use of limestone for this purpose has grown steadily under the impetus of a movement toward accident avoidance in coal mines. In 1936, 53,480 tons were so used. The quantity used passed the 100,000 ton mark in 1941 and exceeded 200,000 tons in 1945.

Magnesium Metal

One of the most striking events in the history of dolomite quarrying was the utilization of this rock during the second World War as an ore of magnesium metal. In 1943, at the height of this activity, 12 companies reported production of 887,830 tons of dolomite for this use. The producing States, in order of importance, were Ohio, Texas, Washington, California, Illinois, Wisconsin, Connecticut, and New York. In 1944, nine companies reported an output of 652,610 tons. In 1945, magnesium-metal production had been cut back so far as a result of the cessation of hostilities that only two companies, both in Ohio, reported output of dolomite for this use, and the total figure is, therefore, concealed.

Dolomitic lime was also used for magnesium-metal manufacture, but the quantity so used was included under sales for all metallurgical applications.

Insecticides, Fungicides, and Disinfectants

An important application of lime which consumes 60,000 to over 80,000 tons a year is the preparation of insecticides and related products. The more important of them, from the standpoint of their lime content, are calcium arsenate, lime-sulfur, and Bordeaux mixture. For calcium arsenate and Bordeaux mixture manufacture, either quicklime or hydrated lime may be used. The quicklime should contain not less than 92.5 percent available calcium oxide and the hydrated lime not less than 90 percent available calcium hydroxide. The lime should contain not more than 1.5 percent magnesium oxide. No specific requirements for lime in lime-sulfur mixture have been established, but the lime should contain very little inert material, and the magnesia content should be low because magnesium compounds readily decompose, producing hydrogen sulfide and liberating sulfur.

Leather

In 1945, 81,213 short tons of lime were sold to tanneries. The use of lime in tanneries is virtually confined to the dehairing (depilation) of the hides. Both quicklime and hydrated lime are used, and the available lime content should be at least 85 percent. High-calcium lime is generally used, but in making Morocco leather high-magnesium lime is employed.

Sewage and Trade-Waste Treatment

Much progress has been made in the treatment of both sewage and the waste water from chemical and industrial plants. Lime is used in conjunction with iron and aluminum salts, for coagulation of solids. It is also used to control the reaction in sludge digestion, to assist in the dewatering process, and to neutralize industrial wastes. In 1939 less than 17,000 tons of lime were applied to these uses; by 1945 the quantity had grown to 71,496 tons. No definite specifications have been established for lime employed in sewage treatment, but a lime as pure as that used in water purification is required.

Poultry Grit

The use of limestone as poultry grit has increased greatly during the past 10 years - from less than 23,000 tons in 1936 to 114,670 tons in 1945. Almost any type of limestone may be so used. It is crushed into granules and screened to uniform sizes.

Petroleum Refining

Lime is used in some refineries to neutralize organic acids present in the petroleum and also to sweeten naphtha and gasoline during the refining process. Grit-free hydrated, high-calcium lime is used to form calcium soaps - important constituents of cup greases, pressure-gun, and cold-set greases. Lime is also used in making candles.

Miscellaneous Processing Industries

Limestone or lime derived from it are used in quantities ranging from a few hundred to several thousand tons a year in a great variety of products and processes. Most of them are given in the second column of table 2 and in the footnotes thereto.

Thus, the production of limestone and its calcination product, lime, is an important industry in spite of the commonplace occurrence of the raw material. The uses of both limestone and lime should expand as new processes are developed. Producers should give constant consideration to methods of treatment or selection that will improve their products for special uses insofar as this is feasible under market conditions. Limestone and lime are low-cost commodities that are likely to replace other materials where-ever substitution is possible.